RESULTS

3.1. Demographic Data

Captains in the Pre-Duty condition averaged 41.3 yr of age and had been employed by their airline for 14.8 yr Captains in the Post-Duty condition averaged 42 yr of age and had been employed for 15 yr. Neither of these differences was statistically significant. Total average flight time for the two groups was also comparable. There were no significant differences on measures related to height, weight, general health, or personality characteristics.

First officers in the Pre-Duty condition averaged 39.1 yr of age and had been employed by the subject airline for 2.3 yr. Post-Duty first officers had a mean age of 39.7 yr. and had been employed for 3 yr. Average airline experience was greater for both groups of first officers since many had been previously employed by other air carriers. None of these differences were statistically significant. No other differences were significant for height, weight, or general health dimensions.

3.2. Fatigue Data

As expected, captains in the Pre-Duty condition had significantly more sleep the night before the experimental runs than did those in the Post-Duty condition--8.46 hr versus 5.71 hr ($t = 4.00$, $p = .001$). Post-Duty captains also reported marginally less sleep two days prior to the simulated flight. Mean sleep times for the previous night were 7.57 hr for Post-Duty captains and 8.82 hr for Pre-Duty captains ($t = 1.64$, $p < .12$). Differences three and four nights before were not statistically significant, which is indicative of the fact that Pre-Duty crews were often on duty during these time periods. Despite differences in the amount of sleep, there were no significant differences in reported sleep quality between the two conditions by captain subjects.

The differences between conditions on the amount of sleep prior to the experiment for first officers were not as robust, but in the same direction. First officers in the Pre-Duty condition averaged 7.55 hr of sleep the night before, while Post-Duty subjects averaged 6.29 hr ($t = 1.96$, $p < .07$). None of the differences for previous nights were statistically significant. As for captains, no sleep-quality differences between conditions were reported for first officers.

On measures of subjective fatigue, no significant differences were evident for captains or first officers on the 10-cm.-line measure of alertness. However, on the 7-point bipolar scale for fresh versus tired, captains in the Post-Duty condition indicated that they were significantly more tired than captains in the Pre-Duty condition ($t = -2.40$, $p < .03$). The same pattern was evident for first officers--Post-Duty subjects reporting more overall "tiredness" ($t = -4.76$, $p < .001$).

Analyses of the mood data generally confirmed that Post-Duty subjects were experiencing more fatigue at the time of the simulation. As in the field study, where mood changes were strongly correlated with with levels of fatigue, Post-Duty subjects tended to report more negative mood ($t = -1.94$, $p = .06$). However, differences on the positive and activation mood indices were not statistically significant.

Taken together, these data would seem to indicate that Post-Duty crewmembers were experiencing significantly more fatigue than Pre-Duty crewmembers. They reported less sleep, more "tiredness", and more negative mood states than did Pre-Duty crewmembers. Though no attempt was made to control for the off-duty activities of Pre-Duty crewmembers (they may have been engaged in fatigue-inducing activity during this off-duty time), it may safely be assumed that these fatigue differences between conditions are associated with the duty cycle.

3.3. Crew Performance Measures

3.3.1. Observer Ratings. In the preflight segment of the simulation scenario, Post-Duty captains were rated better in crew coordination and marginally better in overall performance ($t = -2.81$, $p < .02$; and $t = -1.81$, $p < .09$, respectively), as can be seen in Tables 1 and 2. For first officers in this segment, differences were in the same direction, but not statistically significant. The lack of significant results for first officers on these measures probably reflects the fact that captains are primarily responsible for coordinating preflight activities.

Table 1. Observer Ratings of Captains on Crew Coordination During the Preflight Segment of Simulation

Crew Coordination for Captains		
	Pre	Post
Mean	3.00	3.44
SD	(0.00)	(0.53)
N	11	9

Table 2. Observer Ratings of Captains on Overall Performance During the Preflight Segment of Simulation

Overall Performance for Captains		
	Pre	Post
Mean	2.89	3.22
SD	(0.33)	(0.44)

No significant differences were evident for either captains or first officers in the taxi/takeoff segment. The same pattern was evident during the relatively uneventful climb segment; a slight trend for better rated performance among Post-Duty crewmembers, although these differences were not statistically significant. The only significant measure was for first officer ATC procedures (Table 3), with Post-Duty first officers rated higher on this measure ($t = -2.10$, $p < .05$).

Table 3. Observer Ratings of First Officers on ATC Communication During the Climb Segment of the Simulation

ATC Communication for First Officers		
	Pre	Post
Mean	2.90	3.89
SD	(1.10)	(0.93)

Both coordination and procedures (Tables 4 and 5) were rated better for captains in the Post-Duty condition during the cruise segment ($t = -1.99$, $p < .07$; and $t = -2.22$, $p < .04$, respectively). These differences appear to reflect better handling of the the vigilance measures programmed into this flight phase (icing conditions and moderate turbulence). Mean differences on overall performance for captains in this segment suggested a slight edge for Post-Duty captains, but this difference was not statistically significant.

Table 4. Observer Ratings of Captains on Crew Coordination During the Cruise Segment

Crew Coordination for Captains		
	Pre	Post
Mean	3.27	3.78
SD	(0.47)	(0.67)

Table 5. Observer Ratings of Captains on Procedures During the Cruise Segment

Procedures for Captains		
	Pre	Post
Mean	3.00	3.33
SD	(0.00)	(0.50)

Post-Duty first officers were also rated better on the coordination measure (Table 6) during the cruise segment ($t = -2.58$, $p < .02$). They were also rated as having performed better on the planning dimension (Table 7) in this segment ($t= -2.02$, $p < .06$).

Table 6. Observer Ratings of First Officers on Crew Coordination During the Cruise Segment

Crew Coordination for First Officers		
	Pre	Post
Mean	3.27	3.89
SD	(0.47)	(0.60)

Table 7. Observer Ratings of First Officers on Planning During the Cruise Segment

Planning for First Officers		
	Pre	Post
Mean	2.91	3.56
SD	(0.70)	(0.73)

For the approach segment into RIC, Post-Duty captains were rated better on the approach-planning measure ($t = -2.01$, $p < .06$), as can be seen in Table 8. The coordination rating (Table 9) was marginally significant, with Post-Duty captains again exhibiting better performance ($t = -1.85$, $p =.08$). First officers in the Post-Duty condition were also rated better on the planning measure ($t = -2.07$, $p < .06$), as portrayed in Table 10.

Table 8. Observer Ratings of Captains on Approach Planning Measure During the Approach to RIC Segment

Approach Planning for Captains		
	Pre	Post
Mean	1.91	3.11
SD	(0.94)	(1.69)

Table 9. Observer Ratings of Captains on Coordination Measure During the Approach to RIC Segment

Coordination for Captains		
	Pre	Post
Mean	3.36	4.00
SD	(0.67)	(0.87)

Table 10. Observer Ratings of First Officers on Planning Measures During the Approach to RIC Segment

Planning Measures for First Officers		
	Pre	Post
Mean	1.82	2.78
SD	(0.87)	(1.20)

For the missed-approach and emergency-procedure segment involving the System A hydraulic failure, Post-Duty captains were again rated better on planning and procedure measures ($t = -2.19$, $p < .05$; and $t = -2.10$, $p < .05$, respectively, Tables 11 and 12). The planning rating (Table 13) was also higher for first officers in the Post-Duty condition ($t = -2.32$, $p < .03$). Differences between groups in this flight phase on the planning and procedures measures are particularly significant because they were designed to tap performance during a critically high-workload period of the simulation scenario (dealing with the implications of the hydraulic failure).

Table 11. Observer Ratings of Captains on Planning Measures During the Missed-Approach and Emergency-Procedure Segment

Planning Measures for Captains		
	Pre	Post
Mean	2.91	3.89
SD	(1.14)	(0.78)

Table 12. Observer Ratings of Captains on Procedure Measures During the Missed-Approach and Emergency-Procedure Segment

Procedure Measures for Captains		
	Pre	Post
Mean	3.00	3.56
SD	(0.45)	(0.73)

Table 13. Observer Ratings of First Officers on Planning Measures During the Missed-Approach and Emergency-Procedure Segment

Planning Measures for First Officers		
	Pre	Post
Mean	2.55	3.56
SD	(0.93)	(1.01)

None of the other ratings for cruise-to-alternate and landing were statistically significant, although in several cases the means were in the same direction (higher ratings for crewmembers in the Post-Duty condition).

Taken as a whole, it is particularly significant that all of the reliable differences on this rating measure were in the same direction. This pattern strongly suggests that Post-Duty condition subjects performed better in several phases of flight. While there were many ratings, upon which no statistically significant differences manifested themselves, there was not a single case in which the pattern was reversed--better rated performance by Pre-Duty crewmembers.

3.3.2. Overall Ratings. None of the overall ratings assessed at the end of the simulation approached statistical significance.

3.3.3. Workload Ratings. On subject pilots' own subjective ratings of workload levels experienced in the simulated flights, captains in the Pre-Duty condition felt that they had exerted significantly more mental effort than did captains in the Post-Duty condition ($t = 2.16$, $p < .05$). The workload-rating measure also asked subjects to report how tired they were, and as previously discussed (section 3.2), the Post-Duty captains reported that they were significantly more tired. For first officers, only the fatigue measure was significant.

3.3.4. Aircraft Handling Data. Since the focus of the investigation was upon operational significance, analyses of aircraft handling data were confined to a particular flight segment in which these parameters were expected to be critically important. This segment involved the last few minutes of final approach to ROA where aircraft stability was of the utmost importance since speed, sink rate, and overall stability were expected to be strong predictors of the task of landing the aircraft at a higher-than-normal speed, with reduced braking effectiveness, on a short, wet runway. This was also the culmination of the scenario, where a number of high workload procedures (e.g. manual gear and flap operation) might have conspired to compromise normal aircraft handling performance. The manual control skills involved in aircraft handling were not considered as important at other flight phases (e.g., climb and cruise), because these segments were characterized by low workload (e.g., autopilot usage).

Four measures were used as indicants of stability during this segment; airspeed, vertical speed, localizer, and glideslope deviation. Absolute values were obtained for each measure during the last two min and thirty sec prior to touchdown at ROA--yielding 10 samples of each of the four parameters for all experimental runs. Because of computer problems, complete data were available for only 15 of the 20 experimental runs (9 in the Pre-Duty condition and 6 in the Post-Duty condition). In order to derive an overall index of aircraft stability and because these parameters are intercorrelated, the average for each of the four parameters was computed for each run, and these values were converted to z-scores. The z-scores for each of the parameters were summed yielding an overall index of aircraft stability during the final-approach segment.

Comparison of the stability index between experimental conditions revealed that Pre-Duty crews were significantly more unstable during this final-approach segment than were Post-Duty crews ($t = 2.35$, $p < .05$). Tables 14 and 15 portray the raw values for airspeed and vertical speed, and while these values were not used in the statistical analyses they help in understanding the nature of the effect.

Table 14. Raw Scores for Airspeed (kts) for Pre-Duty and Post-Duty Crews

Airspeed for Pre-Duty and Post-Duty Crews		
	Pre	Post
Mean	152.09	146.95
SD	(8.53)	(3.74)

Given the aircraft weight and 15 degree flap setting, the correct speed in the landing configuration was approximately 135 kts. Since there was a 10-kt. headwind, and since it is a widespread practice to add the extra speed, 145 kts. was the approximate target speed for final approach and landing. Table 14 shows that Post-Duty crews averaged very close to this value (146.94 kts.), whereas Pre-Duty crews were somewhat faster (152.09 kts.).

Table 15. Raw scores for Vertical Speed (ft/min) for Pre-Duty and Post-Duty Crews

Vertical Speed for Pre-Duty and Post-Duty Crews		
	Pre	Post
Mean	858.90	803.17
SD	(157.78)	(106.73)

Precise tracking of the Instrument Landing System (ILS) approach at ROA converts to a vertical descent rate of approximately 800 ft./min. Again, Post-Duty crews were very close to this value (803.17 ft./min.), while Pre-Duty crews averaged a higher vertical sink rate (858.89 ft./min.).

Pre-Duty crews also averaged higher amounts of localizer and glideslope deviation than Post-Duty crews. This corresponds to more horizontal and vertical deviation from the desired approach path to the runway.

3.3.5. Error Analyses. Table 16 summarizes the mean error frequencies for each condition and error type (Types I, II, III, and total errors). None of the differences between error categories or total errors were statistically significant between Pre- and Post-Duty crews. However, mean differences were in the same direction as previous results, particularly on Type III (operationally significant) and total errors. Mean Type III errors for Pre-Duty crews were 4.3 versus 2.33 errors for Post-Duty crews. Pre-Duty crews averaged 9.2 total errors versus 7.0 for Post-Duty crews.

Table 16. Error Frequencies for Pre-Duty and Post-Duty Crews on Type I, Type II, Type III, and Total Errors.

Type I Errors		
	Pre	Post
Mean	1.20	1.56
SD	(1.03)	(1.24)

Type II Errors		
	Pre	Post
Mean	3.70	3.11
SD	(3.56)	(1.54)

Type III Errors		
	Pre	Post
Mean	4.30	2.33
SD	(4.00)	(2.83)

Total Errors		
	Pre	Post
Mean	9.20	7.00
SD	(7.27)	(3.87)

In an effort to better understand this somewhat counterintuitive pattern of findings (tired crews apparently performing better than rested crews) internal analyses were performed. These analyses addressed the fact that Post-Duty crews had typically flown the entire trip together, whereas Pre-Duty crews were typically composed of individuals who may not have flown together recently.

This phenomenon is probably representative of actual operational practice. At the end of a trip, a pilot is more aware of the capabilities and tendencies of other crewmembers than at the beginning of a trip. It was felt that this "crew familiarity" factor may have had some impact on the results.

The reanalyses addressed the familiarity factor. One of the Post-Duty crews did not fly their last trip together prior to simulator evaluation, while two of the Pre-Duty crews had flown together the last time on duty. Thus, all of the data were reanalyzed based on who had flown together the last time on duty. The Pre- versus Post-Duty crew assignment was discarded for the purpose of this analysis. It is important to note that no attempt was made to partition subjects according to whether they knew each other or had ever flown together in the past. In fact, several crews in the "Not Flown Together" condition had flown together at some point in the past. However, the analysis only addressed whether the crewmembers had flown together on the last duty cycle.

The results of one of these reanalyses are presented in Table 17. As can be seen, there were several significant differences apparently attributable to this crew-familiarity factor. The difference between Type I (minor) errors was not significant, however for Type II (moderate) errors, crews that had not flown together averaged significantly more errors (4.78) than did crews that had flown together (2.20) on the last duty cycle ($t = 2.20$, $p < .04$). The same pattern was evident for Type III (major) and total errors. Crews that had not flown together averaged 5.67 Type III errors versus only 1.30 for crews that had flown together, and this difference is highly significant ($t = 3.36$, $p < .004$). There was also a strongly significant difference between these groups on total errors ($t = 2.96$, $p < .009$). Crews that had not flown together averaged 11.67 total errors whereas crews that had flown together averaged less than half (5.0) of this error total.

Table 17. Error Frequencies for Crews that had Flown Together and Not Flown Together on Type I, Type II, Type III, and Total Errors.

Type I Errors		
	Flown	Not Flown
Mean	1.50	1.22
SD	(1.27)	(0.97)

Type II Errors		
	Flown	Not Flown
Mean	2.20	4.78
SD	(1.55)	(3.19)

Type III Errors		
	Flown	Not Flown
Mean	1.30	5.67
SD	(1.34)	(3.87)

Total Errors		
	Flown	Not Flown
Mean	5.00	11.67
SD	(2.58)	(6.60)

In summary, significantly better performance by Post-Duty crewmembers was suggested by all of the various types of crew-performance measures. Many individual parameters were non-significant, but there were no reversals of this general pattern. It appears that much of this performance difference is due to the fact that Post-Duty crews, since they were tested at the end of their duty cycle, were more likely to have operated together.

3.4. Crew Communication Analyses

Extensive analyses of the crew communications process were undertaken since these variables represent perhaps the best reflection of how the crew coordinates its activities. Therefore, it was expected that these communications measures would facilitate the understanding of the performance effects, as has been suggested in the past (e.g., Foushee, 1984).

Two types of analyses were performed. First, a 2 x 2 (Pre- vs. Post-Duty x captain vs. first officer) between-subjects analysis-of-variance (ANOVA) was performed for each category as well as for total communication. The second type of analysis was designed to look at communication variables as they were affected at different phases of flight. It involved a 2 x 2 x 3 (Pre- vs. Post-Duty x captain vs. first officer x phase of flight) mixed-design ANOVA, also performed for each category. The three-factor phase-of-flight parameter was a within-subjects variable, and was broken down in the following manner: 1) the 10-min period immediately after rotation that was completely routine; 2) the 10-min period beginning after the decision to execute a missed approach; and 3) the 10-min period immediately prior to touchdown at ROA. Thus, one relatively low-workload period and two relatively high-workload periods were included in these analyses.

Since the familiarity variable appeared to be strongly related to crew performance in this study, the same analyses were conducted incorporating this factor. Both the 2 x 2 between subjects ANOVAs and the 2 x 2 x 3 mixed-design

ANOVAs were identical except that the Flown Together-Not Flown Together variable was substituted for the Pre-Post Duty variable.

3.4.1. Commands. The 2 x 2 x 3 ANOVA for commands revealed a significant main effect for the Pre-Post variable ($F(1.32) = 4.07$, $p = .05$), indicating that in general Post-Duty crewmembers exchanged more commands, and this was true of both captains and first officers in this condition. Not surprisingly, captains utilized this form of communication more often than did first officers ($F(1,32) = 107.34$, $p < .001$). It has been suggested elsewhere (e.g., Foushee & Manos, 1981) that commands appear to have a coordinating effect on crew performance because of their strong influence on subordinate crewmember actions. Commands were much more predominant during high workload phases of flight ($F(2,64) = 37$, $p < .01$). It is also interesting to note that first officers who had recent operating experience with the captain they were flying with were more likely to use command-type statements. Increased familiarity may raise the probability that subordinate crewmembers will be more assertive when the circumstances call for such behavior. These results are summarized in Table 18.

Table 18. Means and Standard Deviations (SDs) of Commands for Captains and First Officers in Pre-Duty and Post-Duty Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed-Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Commands				
	Pre- Capt	Pre- F/O	Post- Capt	Post- F/O
Mean (ROT)	10.00	0.00	15.56	0.22
SD	(2.78)	(0.00)	(6.56)	(0.44)
Mean (MA)	13.33	0.44	19.44	0.11
SD	(4.74)	(0.73)	(10.31)	(0.33)
Mean (TD)	12.89	0.56	17.44	1.22
SD	(3.82)	(0.88)	(7.70)	(1.56)

The same pattern was evident for commands on the 2 x 2 ANOVAs and on the 2 x 2 x3 ANOVAs on the familiarity factor. In short, performance appeared to be facilitated by the more prevalent usage of commands by captains in the Post-Duty condition, particularly during high workload phases of flight.

3.4.2. Observations. The analyses for the variable, observations about flight status, revealed a significant main effect for crew position ($F(1,32) = 14.84$, $p < .001$). This effect was due to the fact that first officers utilize this category of communication more frequently than captains as can be seen in Table 19. This is logical in light of the support role assigned to first officers in flight duties, since observations about flight status are a primary means of providing information for the captain to act upon. The main effect for phase-of-flight was significant ($F(2,64) = 13.23$, $p < .001$) indicating more observations during high-workload periods. The interaction of crew position and flight segment was also significant ($F(2.64) = 3.23$, $p < .05$) and is due to the more prevalent use of this category of communications by first officers during high-workload phases.

Table 19. Means and SDs of Observations for Captains and First Officers in Pre-Duty and Post-Duty Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed Ppproach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Observations				
	Pre- Capt	Pre- F/O	Post- Capt	Post- F/O
Mean (ROT)	12.89	20.33	19.11	22.33
SD	(7.18)	(7.97)	(13.46)	(4.64)
Mean (MA)	12.11	23.33	17.33	23.56
SD	(6.41)	(8.76)	(9.08)	(10.88)
Mean (TD)	19.78	29.67	18.11	33.44
SD	(5.65)	(7.02)	(5.90)	(10.89)

3.4.3. Suggestions. For the category, suggestions, the main effect for crew position was again significant ($F(1,32) = 26.97$, $p < .001$), with captains responsible for more suggestions than first officers (Table 20). This is likely reflective of the captain's role in directing subordinate behavior, as suggestions are probably a "softer" means of providing directions than commands. The crew position by crew familiarity interaction approached statistical significance ($F(1,32)$, $p < .09$). Captains who had flown with the same first officer tended to offer more suggestions than those who had not (Table 21). This may imply a somewhat less "directive" style among captains who are relatively familiar with other crewmembers on the flightdeck, since suggestions tend to be less directive.

Table 20. Means and SDs of Suggestions for Captains and First Officers in Pre-Duty and Post-Duty Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed-Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Suggestions				
	Pre- Capt	Pre- F/O	Post- Capt	Post- F/O
Mean (ROT)	2.78	0.89	3.56	0.89
SD	(3.07)	(0.93)	(3.24)	(0.78)
Mean (MA)	3.67	0.56	4.33	1.22
SD	(2.65)	(0.73)	(2.12)	(1.99)
Mean (TD)	4.67	1.56	3.89	1.56
SD	(2.35)	(1.74)	(2.26)	(1.42)

Table 21. Means and SDs of Suggestions for Captains and First Officers in Flown Together (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed-Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Suggestions				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	4.30	0.90	1.75	0.88
SD	(3.65)	(0.88)	(1.39)	(0.83)
Mean (MA)	4.80	0.90	3.00	0.88
SD	(2.04)	(1.91)	(2.45)	(0.83)
Mean (TD)	4.50	1.40	4.00	1.75
SD	(2.37)	(1.43)	(2.27)	(1.75)

3.4.4. Statements of Intent. This was another category which was assumed to reflect the amount of overall coordination. These communications are generally utilized to inform others of the actions that the speaker is about to undertake, and thus keep other crewmembers informed. Again, the main effect for crew position was significant ($F(1,34) = 9.6$, $p < .004$). First officers exhibited this form of communication more frequently than captains, but the crew-familiarity main effect was also marginally significant ($F(1,34) = 3.58$, $p < .07$). Statements of intent were relatively more prevalent among crewmembers who had flown together, as Table 22 portrays. This suggests one reason for coordination deficiencies that were apparent in the Pre-Duty or Not Flown Together conditions and may be in part responsible for the performance differences seen on previous measures.

Table 22. Means and SDs of Statements of Intent for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Statements of Intent		
	Flown	Not Flown
Capt Mean	8.90	3.67
SD	(6.40)	(2.12)
F/O Mean	14.20	11.44
SD	(7.24)	(8.35)

3.4.5. Inquiries. These are information-seeking behaviors designed to elicit assistance from other crewmembers. Mean differences can be seen in Tables 23 and 24. Captains sought more information than first officers ($F(1,34 = 3.87$, $p < .06$), but this type of information-seeking behavior was far more prevalent during high workload phases of flight ($F(1,32) = 9.81$, $p < .001$). Neither the fatigue variable, nor the crew familiarity variable predicted any of the differences on this measure.

Table 23. Means and SDs of Inquiries for Captains and First Officers in Pre-Duty and Post-Duty Crews

Means and SDs of Inquiries		
	Pre-Duty	Post-Duty
Capt Mean	30.80	36.44
SD	(9.30)	(20.18)
F/O Mean	27.20	22.56
SD	(12.03)	(11.37)

Table 24. Means and SDs of Inquiries for Captains and First Officers in Flown Together (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed-Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Inquiries				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	9.60	5.80	8.13	6.50
SD	(4.55)	(3.94)	(3.94)	(2.45)
Mean (MA)	13.10	7.40	11.25	11.13
SD	(9.69)	(4.93)	(4.71)	(5.38)
Mean (TD)	10.40	6.60	11.00	9.88
SD	(4.74)	(2.72)	(5.24)	(3.72)

3.4.6. Agreement. No differences on the agreement variable were statistically reliable, but it should be noted that agreement was an infrequently occurring category.

3.4.7. Disagreement. On instances of verbal communication reflecting the disagreement of one crewmember with the actions, intended actions, or statements of another, significant two-way interactions were obtained with the crew position variable on both the familiarity and the fatigue variables, and the mean differences for this category can be seen in Tables 25 and 26. In both cases, first officers were largely responsible for this effect. First officers in the Post-Duty condition were far more likely to disagree with the actions of captains ($F(1,34) = 6.20$, $p < .02$). The same was true for first officers who had flown with the same captain previously, only the effect was stronger ($F(1,34) = 11.37$, $p < .002$). It has been suggested that first officers, because of the role structure of the flightdeck, are often hesitant to question or correct the actions of captains and that this reluctance has been a factor in a substantial number of incidents and accidents (e.g. Cooper, White, & Lauber, 1979; Foushee & Manos, 1981; and Foushee, 1984). This result suggests that crewmember familiarity may mediate against this hesitancy and raises the probability that familiar first officers or subordinates will be more assertive when the circumstances call for such behavior.

Table 25. Means and SDs of Disagreements for Captains and First Officers in Pre-Duty and Post-Duty Crews

Means and SDs of Disagreements		
	Pre-Duty	Post-Duty
Capt Mean	1.70	0.78
SD	(1.70)	(0.67)
F/O Mean	0.60	2.00
SD	(0.70)	(2.12)

Table 26. Means and SDs of Disagreements for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Disagreements		
	Flown	Not Flown
Capt Mean	0.70	1.89
SD	(0.67)	(1.69)
F/O Mean	2.10	0.33
SD	(1.91)	(0.50)

3.4.8. Acknowledgements. Past research has demonstrated that acknowledgements to other communications are often associated with fewer crew-performance errors, and that these categories of communication tend to reinforce the interaction process (e.g. Foushee & Manos, 1981). The same was true in the present investigation. Acknowledgements were significantly more prevalent in crews that had flown together ($F(1,34) = 8.33$, $p < .007$), as Table 27 suggests. Acknowledgements were also seen more frequently in high workload segments of flight ($F(2,64) = 3.35$, $p < .05$), suggesting that they play an even more important role in the communications process during critical phases of flight (Table 28).

Table 27. Means and SDs of Acknowledgements for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Acknowledgements		
	Flown	Not Flown
Capt Mean	46.70	33.89
SD	(12.86)	(17.45)
F/O Mean	59.30	41.33
SD	(20.52)	(13.44)

*Table 28. **Means** and SDs of Acknowledgements for Captains and First Officers in Flown Together (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed- Approach (MA), and 10-min Prior to Touchdown (TD)*

Means and SDs of Acknowledgements				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	11.90	16.10	10.25	10.25
SD	(4.28)	(8.97)	(4.20)	(5.01)
Mean (MA)	15.00	16.60	9.25	10.63
SD	(6.24)	(7.28)	(6.94)	(4.14)
Mean (TD)	15.50	17.60	11.00	13.50
SD	(6.65)	(5.48)	(6.23)	(5.18)

3.4.9. Answer Supplying Information. **Responses to requests for information were more prevalent among first officers ($F(1,34) = 3.99$, $p < .06$). This is not surprising since by definition, these behaviors are usually responses to commands, inquiries or observations that are more likely to come from the captain. First officers in the Post-Duty condition were more likely to exhibit this type of behavior ($F(1,34) = 3.84$, $p < .06$), as were first officers who had recent operating experience with their captains ($F(1,34) = 3.38$, $p < .07$). These results are summarized in Tables 29 and 30, and again imply that more overall information exchange occurred in crews with recent operating experience together.**

Table 29. Means and SDs of Answers Supplying Information for Captains and First Officers in Pre-Duty and Post-Duty Crews

Means and SDs of Answers Supplying Information		
	Pre-Duty	Post-Duty
Capt Mean	17.80	11.44
SD	(6.43)	(4.16)
F/O Mean	17.90	21.67
SD	(7.75)	(11.72)

Table 30. Means and SDs of Answers Supplying Information for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Answers Supplying Information		
	Flown	Not Flown
Capt Mean	12.40	17.33
SD	(4.30)	(7.35)
F/O Mean	21.90	17.22
SD	(10.34)	(8.94)

*3.4.10. **Response Uncertainty.*** No differences were evident as a function of any of the independent variables on this measure. There was a marginal tendency for more of this type of behavior in high workload flight phases, although it was not statistically significant ($F(1,32) = 2.43$, $p < .10$). Response uncertainty was infrequently verbalized by crewmembers, but communication coders anecdotally reported non-verbal indications. Such data were not systematically obtained because of their inherent unreliability.

*3.4.11. **Tension Release.*** This category was operationalized as a reflection of non-task-related behavior and typically consisted of laughter or humorous remarks. A significant main effect for the crew-familiarity variable was evident on this measure ($F(1,34) = 4.14$, $p < .05$), as can be seen in Table 31. There was significantly more tension release among crewmembers who had not flown together prior to the simulator sessions. This difference may be a reflection of the acquaintance process for crewmembers unfamiliar with each other. However, as can be seen in Table 32, this difference was primarily evident for the low workload segment and diminished significantly during the high workload flight segments ($F(2,64) = 8.0$, $p < .002$).

Table 31. Means and SDs of Tension Releases for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Tension Releases		
	Flown	Not Flown
Capt Mean	3.40	10.00
SD	(3.89)	(11.55)
F/O Mean	5.20	8.89
SD	(6.97)	(7.24)

*Table 32. **Means** and SDs of Tension Releases for Captains and First Officers in Flown **Together** (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min **After** Rotation (ROT), 10-min **After** Missed- Approach (MA), and 10-min Prior to Touchdown (TD)*

Means and SDs of Tension Releases				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	1.90	2.60	4.88	5.00
SD	(2.64)	(4.12)	(6.64)	(4.38)
Mean (MA)	0.80	1.10	2.63	1.50
SD	(1.40)	(1.20)	(4.17)	(3.46)
Mean (TD)	0.80	1.30	1.75	2.00
SD	(1.14)	(1.16)	(2.05)	(1.85)

3.4.12. ***Frustration/Anger.*** **Captains exhibited considerably more of this type of behavior than did first officers (Table 33) regardless of experimental condition ($F(1,34) = 11.58$, $p < .002$). Phase of flight was also a significant predictor as might have been expected ($F(2,64) = 3.76$, $p < .03$). Table 34 suggests that this difference is attributable to the fact that more frustration occurred during the high workload phases of flight. The fact that captains are more prone to this type of behavior is no doubt strongly tied to the captain's authority role.**

Table 33. Means and SDs of Frustration for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Frustration		
	Flown	Not Flown
Capt Mean	4.50	5.89
SD	(3.87)	(7.20)
F/O Mean	0.10	1.22
SD	(0.31)	(1.64)

Table 34. Means and SDs of Frustration/Anger for Captains and First Officers in Flown Together (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Frustration/Anger				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	0.90	0.00	1.13	0.00
SD	(1.85)	(0.00)	(1.13)	(0.00)
Mean (MA)	1.70	0.00	2.25	0.13
SD	(1.89)	(0.00)	(4.10)	(0.35)
Mean (TD)	1.60	0.10	2.63	1.13
SD	(1.51)	(0.32)	(4.14)	(1.73)

3.4.13. Embarrassment. This type of behavior typically consisted of apologetic remarks as a result of mistakes or oversights on the part of one crewmember. None of the main effects for any of the experimental variables were significant, but a marginally significant two-way interaction between the crew familiarity variable and phase of flight was found ($F(2,64) = 3.12$, $p < .06$). This type of behavior was more often seen among crewmembers who had not previously flown together during the high workload phases of flight, as can be seen in Table 35. This finding appears consistent with the performance profiles of crewmembers in this condition. Crewmembers who had not flown together made significantly more serious errors.

Table 35. Means and SDs of Embarrassment for Captains and First Officers in Flown Together (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed- Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Embarrassment				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	0.50	0.10	0.13	0.38
SD	(1.27)	(0.32)	(0.35)	(0.52)
Mean (MA)	0.20	0.30	0.13	0.13
SD	(0.42)	(0.48)	(0.35)	(0.35)
Mean (TD)	0.00	0.20	0.63	0.50
SD	(0.00)	(0.42)	(0.74)	(0.53)

3.4.14. Non-Task-Related Communication. This category included crew interaction that was clearly not related to flight tasks. On this measure, the main effect for crew familiarity was significant ($F(1,32) = 7.29$, $p < .02$). Crews that had not flown together engaged in more non-tasked-related interaction than crews that had flown together, which may be related to the fact that they were probably becoming acquainted. This was more apparent during low workload periods of flight since the main effect for flight phase was also strongly significant ($F(2,64) = 7.18$, $p < .002$). The two-way interaction between phase of flight and crew familiarity was also significant ($F(2,64) = 4.26$, $p < .02$), indicating that non-task-related interaction was far more prevalent among crewmembers that had not flown together during low workload periods. The means for these analyses are shown in Table 36.

Table 36. Means and SDs of Non-Task-Related Communication for Captains and First Officers in Flown together (Ft) and Not Flown Together (Nf) Crews for Three Phases of Flight - 10-min After Rotation (ROT), 10-min After Missed-Approach (MA), and 10-min Prior to Touchdown (TD)

Means and SDs of Non-Task-Related Communication				
	Ft Capt	Ft F/O	Nf Capt	Nf F/O
Mean (ROT)	0.40	0.20	2.00	2.13
SD	(0.70)	(0.42)	(3.21)	(3.48)
Mean (MA)	0.20	0.00	0.13	0.13
SD	(0.63)	(0.00)	(0.35)	(0.35)
Mean (TD)	0.00	0.00	0.25	0.25
SD	(0.00)	(0.00)	(0.46)	(0.71)

3.4.15. Repetitions. This category was intended to reflect instructions from one crewmember to another that were repeated in quick succession. Communications of this type are typically used to convey a sense of urgency or to assure that an instruction has been received by the crewmember to whom it was addressed. None of the main effects were significant, but the interaction between the crew position and the fatigue variables was statistically significant ($F(1,34) = 4.59$, $p < .04$), as can be seen in Table 37. Post-Duty captains repeated instructions more often than either captains in the Pre-Duty condition or first officers in either condition. This finding may explain, in part, the apparently better coordination among Post-Duty crewmembers who were previously acquainted, since repetitions may have assured that critical pieces of information were transferred between crewmembers at appropriate times. The 2 x 2 x 3 ANOVAs were not performed on this measure because of insufficient instances of this behavior across all of the flight phases.

Table 37. Means and SDs of Repetitions for Captains and First Officers in Pre-Duty and Post-Duty Crews

Means and SDs of Repetitions		
	Pre-Duty	Post-Duty
Capt Mean	1.00	2.44
SD	(0.67)	(1.51)
F/O Mean	1.80	1.56
SD	(1.23)	(1.33)

3.4.16. Checklist Items. These communications were merely the challenges issued on standard procedural checklists required at various flight phases. No effects for the fatigue or crew familiarity variables were evident, however the main effect for crew position was significant ($F(1,34) = 30.35$, $p < .001$). First officers were responsible for most of these communications (Table 38), which is entirely logical since they were assigned non-flying pilot duties for the simulation.

Table 38. Means and SDs of Checklist Items for Captains and First Officers in Pre-Duty and Post-Duty Crews

Means and SDs of Checklist Items		
	Pre-Duty	Post-Duty
Capt Mean	7.60	7.44
SD	(1.96)	(2.65)
F/O Mean	12.70	13.44
SD	(2.79)	(4.56)

3.4.17. Air Traffic Control Communications. Once again, the main effect for crew position was significant ($F(1,34) = 256.93$, $p < .001$), with first officers almost entirely responsible for ATC communication (Table 39). As with checklist duties, ATC communications are almost entirely the responsibility of the non-flying pilot.

Table 39. Means and SDs of ATC Communications for Captains and First Officers in Pre-Duty and Post-Duty Crews

Means and SDs of ATC Communications		
	Pre-Duty	Post-Duty
Capt Mean	7.50	8.89
SD	(8.48)	(10.91)
F/O Mean	75.60	80.22
SD	(10.63)	(20.85)

3.4.18. Total Communication. It was expected that total communication, or the sum of all types of communication including non-codable verbal behavior throughout the simulated flight, would be related to overall performance (e.g. Foushee & Manos, 1981). This was suggested in the present investigation as the main effect for the crew familiarity variable was marginally significant ($F(1,34) = 3.55$, $p < .07$). Overall, communication was more frequent in crews that had flown together than in crews that had not, as Table 40 reveals. This is particularly interesting in light of the significant performance differences between these groups. First officers exhibited more overall communication than captains ($F(1,34) = 4.72$, $p < .04$), and this is most likely due to the fact that first officers, in their non-flying role, were more involved in supplying task-relevant information for captains' use in decision-making.

Table 40. Means and SDs of Total Communication for Captains and First Officers in Flown Together and Not Flown Together Crews

Means and SDs of Total Communication		
	Flown	Not Flown
Capt Mean	335.40	285.89
SD	(79.03)	(53.22)
F/O Mean	369.90	341.33
SD	(59.42)	(58.60)

The 2 x 2 x 3 ANOVAs were not performed because the three-level flight phase variable did not encompass the entire time period involved in the simulated flight. Thus, this analysis was not an accurate representation of total communications in the simulated flight.

3.4.19. Communications Summary. In general, the communications variables, as measures of group interaction and coordination, reflected the same trends evident for the crew performance measures. Post-Duty crews and crews that had flown together engaged in more task-related communication and less non-task related communication. As expected, instances of various communications behaviors increased with increasing task demands. These analyses appeared to support the conclusion that the performance differences seen in this study were in large part caused by differences in crew coordination. This conclusion is based on the assumption that crew communication patterns are at least partial reflections of the coordination process, since they are the means by which many individual efforts are coordinated. Crews that had flown together seemed better able to coordinate their activities than crews that had not flown together.